

# Shadowing of Gluons at RHIC and LHC <sup>1</sup>

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## Abstract

We show estimates for shadowing of gluons at small values of  $x$ , appropriate to RHIC and LHC experiments. Using a new evolution equation which takes into account the effects of gluon recombination to all orders in gluon density, we show that there is a significant depletion in the gluon density of large nuclei.

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# 1 Introduction

Understanding the initial conditions of a relativistic heavy ion collision from first principles is perhaps the single most challenging problem facing the heavy ion community. Proposed signatures of a possible Quark-Gluon Plasma (QGP) formed in heavy ion collisions will crucially depend on the initial conditions. At the very early stages of the collision, one would need to take the full quantum mechanical nature of the nuclei into account which is a prohibitingly difficult task since it would require full knowledge of the nuclear wave functions. The McLerran-Venugopalan model [1] offers a new and promising tool to investigate these early times by representing the initial nuclei by classical fields. At later times, when the highly off-shell modes of the field are freed by hard scattering and go on-shell, one can identify these modes with partons and consider the initial distributions of these partons in the nuclei.

When calculating a typical nuclear cross section, one needs to know the distribution of a given parton kind in the nucleus  $f_{g/A}$ . Using the QCD factorization theorems, one can then write the nuclear cross section as a convolution of the nuclear parton densities with the hard parton-parton cross section, i.e.

$$\sigma_{AB} \sim f_{g/A}(x, Q) \otimes \sigma_{gg} \otimes f_{g/B}(x, Q) \quad (1)$$

In order to obtain the nuclear parton distributions, one can take the corresponding parton distributions in a nucleon and scale them by the atomic weight  $A$ . This sounds plausible specially at high values of  $Q^2$  since one does not expect nuclear effects to be important at large values of  $Q^2$ . However, this expectation was proved to be too naive and it was experimentally found the the distribution of partons in free nucleons are strikingly different from those in bound nucleons. This difference is more pronounced in large nuclei at small values of  $x_{bj}$  where a significant depletion in the number of partons is observed so that a simple  $A$  scaling does not hold.

Alternatively, one could measure the nuclear parton distribution in a particular experiment. Since these distributions are universal, one could then use them to predict nuclear

cross sections in other experiments. The most recent experiments measuring nuclear parton distributions have been performed by the NMC collaboration at CERN SPS [2] and by the E665 collaboration at Fermilab [3]. However, both of these are fixed target experiments and are limited in the kinematic range in  $x$  and  $Q^2$  they can cover. Also, the amount of data in the kinematic region where perturbative QCD would apply is limited. A lepton-nucleus collider would go a long way towards expanding our knowledge of the nuclear parton distributions and is urgently needed.

Once the nuclear parton distributions are known at a given value  $x_0$  and  $Q_0$ , one can use the perturbative QCD evolution equations to predict the distributions at different  $x$  and  $Q$ . However, the standard evolution equations are expected to break down at very small values of  $x$  due to parton recombination effects. A new evolution equation (JKLW) which takes these effects into account was derived in [4] and is the non-linear all twist generalization of the standard perturbative QCD evolution equations such as DLA DGLAP and GLR/MQ (see also [5] for a similar equation). These non-linear effects were investigated numerically in [6] and were found to be important in the kinematic region to be explored by the upcoming experiments at RHIC and LHC. One can also use this new evolution equation to predict the  $x$ ,  $Q$ ,  $b_t$  and  $A$  dependence of the gluon shadowing ratio defined as

$$S = \frac{xG_A}{AxG_N} \quad (2)$$

where  $xG_A$  and  $xG_N$  are the nuclear and nucleon gluon distribution functions respectively.

## 2 Shadowing of gluons

To calculate the shadowing ratio  $S$  for gluons, we start with the following evolution equation which was derived from the effective action for QCD at small  $x$  in [4].

$$\frac{\partial^2}{\partial y \partial \xi} xG(x, Q, b_\perp) = \frac{N_c(N_c - 1)}{2} Q^2 \left[ 1 - \frac{1}{\kappa} \exp\left(\frac{1}{\kappa}\right) E_1\left(\frac{1}{\kappa}\right) \right] \quad (3)$$

where

$$\kappa = \frac{2\alpha_s}{\pi(N_c - 1)Q^2} xG(x, Q, b_\perp) \quad (4)$$

and  $E_1(x)$  is the exponential integral function defined as [7]

$$E_1(x) = \int_0^\infty dt \frac{e^{-(1+t)x}}{1+t}, \quad x > 0 \quad (5)$$

This equation was shown to reduce to DLA DGLAP and GLR/MQ at the low gluon density limit. In [6] we showed in detail how to solve this equation numerically. Here, we briefly review our main approximations and assumptions and refer the interested reader to [6] for more details. In order to solve equation (3), we need to know the initial gluon distribution at some reference point  $x_0$  and  $Q_0$  as well as its derivative (this is due to making the semi-classical approximation). We then use a fourth order Runge-Kutta code to calculate the gluon distribution at any other point  $x$  and  $Q$ . In [6], we took  $x_0 = 0.05$  and  $Q_0 = 0.7$ , but the effective  $Q_0$  for most points calculated was about  $1\text{GeV}$ . The reason for our choices were two fold; first that experimentally it is known that the shadowing ratio is about 1 in the range  $x = 0.05 - 0.07$ . Also, in order to maximize the effects of perturbative shadowing, we needed to start from as low value of  $Q_0$  as possible while keeping it high enough so that perturbative QCD is still valid. With these approximations, we showed in [6] that for large nuclei, the non-linearities of the evolution equation are very important. Our results for the gluon shadowing ratio as defined in (2) are shown in Figure 1. It is clear that gluon shadowing at RHIC and LHC will be important.

Shadowing of gluons in nuclei will have significant effects on the measured observables in the upcoming experiments at RHIC and LHC. For example, initial minijet and total transverse energy production will be greatly reduced. Also, heavy quark production will be significantly effected since its cross section is proportional to the squared of gluon density. Basically, any production cross section which involves the distribution of gluons in nuclei will be modified. Therefore, it is extremely important to understand shadowing more thoroughly. For example, the observed shadowing ratio (of  $F_2$ ) does not seem to have a significant  $Q$  dependence while parton recombination models tend to predict a strong  $Q$  dependence of the shadowing ratio. This could in principle be due to assuming no shadowing at the initial point, i.e. the point where the perturbative evolution starts from. To investigate this, one should include initial non-perturbative shadowing at the reference

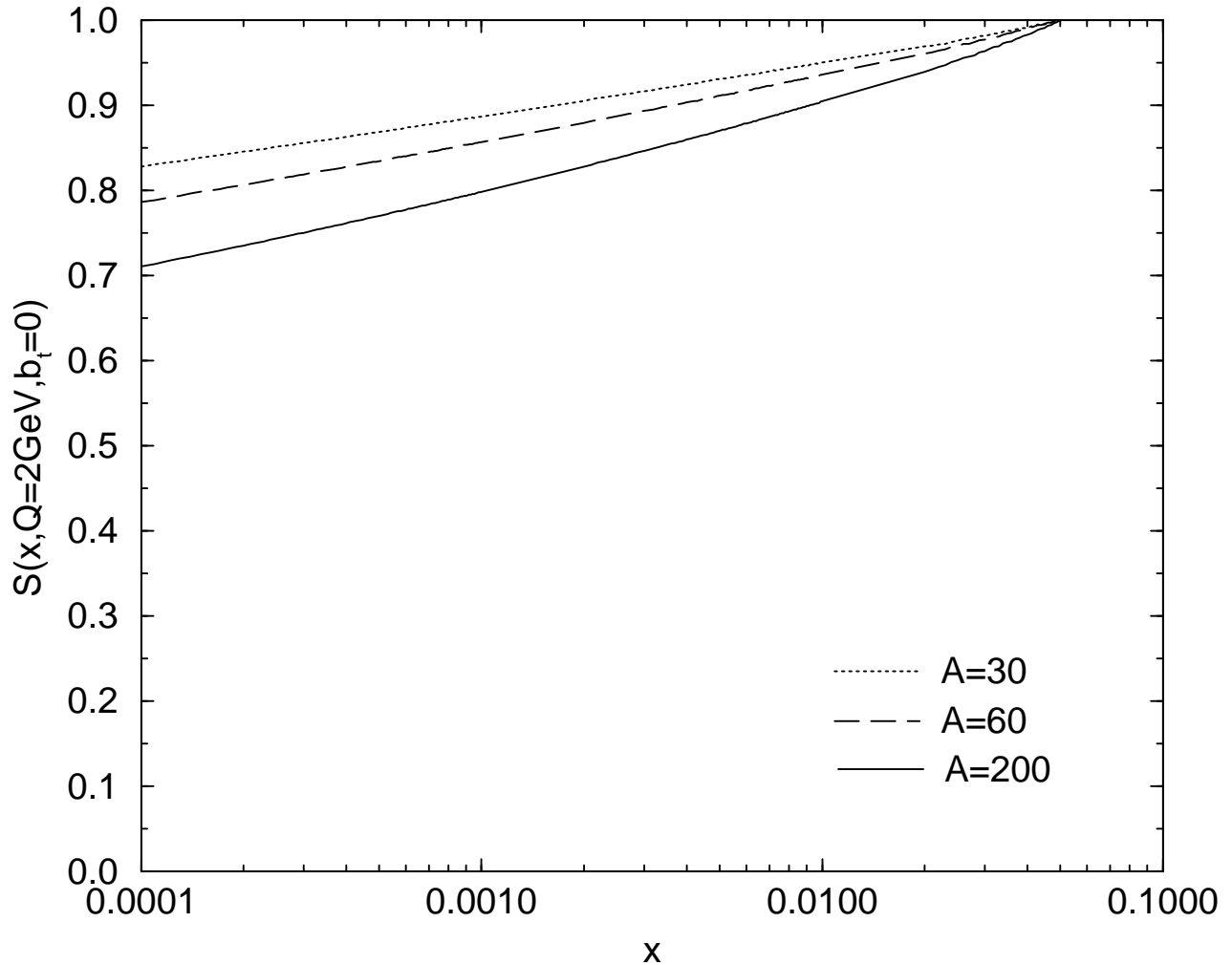


Figure 1: Gluon shadowing as defined in (2)

point and then evolve the distributions with both the leading twist DGLAP and all twist JKLW evolution equations. The difference between the two would be a clear indication of importance of higher twist effects in understanding gluon shadowing.

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